DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 202

PROBLEM: 1

Problem 1

a) What is the name and function of the circuit shown in Figure 1? (1 point)

With the following assumptions, answer parts b-g. If you are making any other assumptions/approximations, clearly mention them in your answers.

I_{TAIL}=80µA

For both PMOS and NMOS:

λ=0.03 V^{-1}, |Vth|=0.7 V, $\mu_n C_{ox}$=120 µA/V^2, $\mu_p C_{ox}$=40 µA/V^2 , γ =0

W/L (NMOS)=40 and W/L (PMOS)=80

Parasitic capacitance: C_X=0.1 pF, C_Y=0.05 pF

C_{Load}=0.5 pF

b) What is the output resistance? (4 points)

c) What is the small signal voltage gain (v_{out}/v_i)? (4 points)

d) How many poles does the system have? Calculate each pole in Hz (4 points)

e) What's the bandwidth of the system? (2 points)

f) Does the system have a zero? Briefly explain your answer) (2 points)

g) Draw the Bode plot of magnitude and phase (3 points)

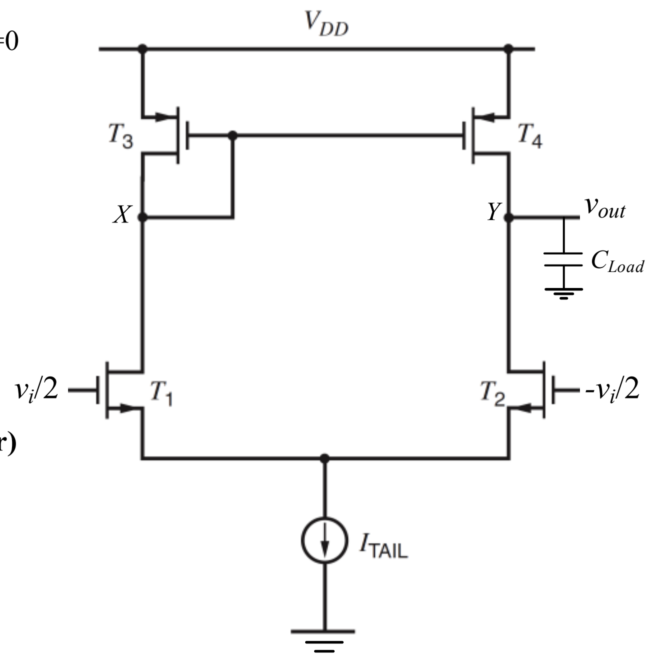


Figure 1

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 202

PROBLEM: 2

Problem 2

a) What is the name and function of the circuit shown in figure 2? (2 points)

For parts b-e, ignore body effect (γ=0). Do not ignore channel length modulation ($\lambda \neq 0$)

b) What is the output resistance? (4 points)

c) What is the small signal voltage gain? (5 points)

d) Which devices do not have significant contribution to input referred noise? Why? (2 points)

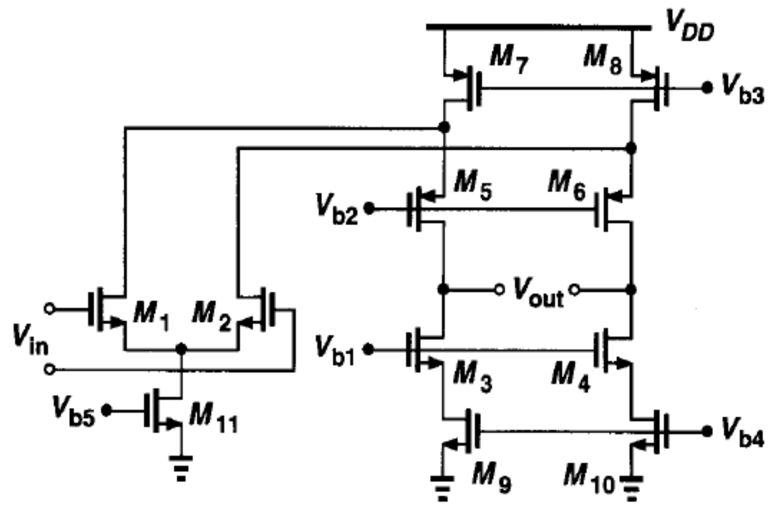


Figure 2

e) Find the total input referred thermal noise. (Hint: for some devices, it might be easier to first find the output referred noise and then use it to find the input referred noise) (5 points)

f) Redraw this circuit such that the input stage (M1 and M2) are PMOS devices. (2 points)

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 203

PROBLEM: 1

1. You have been selected as main integration engineer in a semiconductor foundry. Your first task consists on completing a baseline process for MOSFET fabrication, as an introduction you have been shown the progress that your predecessor made in building the baseline. However, the existing process has some errors, which made the transistors not work as expected. Below you will find some of the main points that need to be fixed for the transistors to work properly. Please state your solution from a fabrication point of view. (For simplicity assume that each problem is for different fabrication batches and they are not related with each other)

1a) When you test the transistor you realize in the $I_D V_G$ curve that current is constant at the maximum current your test bench can provide. State the reason or reasons for the problem and the solution. (2 Points)

1b) You find that when the transistors are being tested they break down (gate and source electrically short) at very low bias voltages, when you back to the process notes you find that the gate silicon dioxide was grown in a furnace and that the gate conductor consists of heavily doped poly-Si deposited using PECVD system at 650 ˚C. State the reason for the problem and the solution. (2 Points)

1c) In the final steps of the process you see the following sequence:

I. Ni deposition
II. Silicidation Anneal
III. Piranha etch
IV. Al deposition
V. Al etch
VI. Test

When you test the transistor you find that the transistor is giving high leakage current and an ON state current lower than expected. When you check the process again you find that there is a missing step in process. State which step is missing and where it should be placed. (2 Points)

1d) When you test the transistors you see that there is no modulation at the bias voltages you expected the transistor to work (no on/off behavior). You go back to check the fabrication process and you see the following steps for the fabrication of NMOSFETs.

I. Ar heavily doped Si (100) as substrate
II. RCA cleaning
III. Si oxidation to target 400nm using a furnace and dry-wet-dry oxidation process
IV. Mesa photolithography using positive ECI3027 photoresist and a exposure dose of 200 mJ/cm^2
V. Mesa etch (open holes in SiO_2 to expose Si) using RIE system with the following recipe - RIE: 1500 W_{ICP}, 100 W_{RF}, 10 mTorr, 5 sccm O_2, 40 sccm CHF_3
VI. Vapor HF passivation for 30 seconds at 40 ˚C

Continued on the next page

VII. High-k and metal gate deposition to deposit Al_2O_3 with TMAH as Al precursor and TiN with TICL as Ti precursor

VIII. Poly-Si deposition with SiH_4 as silicon precursor

IX. Gate photolithography with AZ1512 as photoresist and exposure dose of 40 mJ/cm^2

X. Gate etch using RIE system with the following recipe - RIE: 2000 W_{ICP}, 50 W_{RF}, 10 mTorr, 10 sccm SF_6, 90 sccm CHF_3 (Consider this step etches the entire gate)

When you check those first 10 steps you see that something does not seem right. Which step is causing the transistor to exhibit no on/off behavior and what should be the solution. (2 Points)

1e) You have made many changes to the fabrication process and the transistors are finally working. You are really exited about your amazing results and show them to your boss. Even though the transistors work as expected your boss tells you that there have been some budget problems and that the fabrication process cost needs to be reduced by 10%. The costs are as follows for single polarity transistors: (2 Points)

- Etching - 50 USD
  - MESA - 10 USD
  - GATE – 20 USD (for the entire gate)
  - SPACER – 10 USD
  - CONTACS – 10 USD
- Deposition – 50 USD
  - GATE – 20 USD (for the entire gate)
  - SPACER – 10 USD
  - NICKEL – 10 USD
  - ALUMINUM – 10 USD
- Lithography - 50 USD (lithography costs are negligible except for mask count, only mask count taken into account below)
  - MESA MASK – 10 USD
  - GATE MASK – 10 USD
  - SILICIDATION MASK – 10 USD
  - SPACER MASK – 10 USD
  - CONTACT MASK – 10 USD
- Rest of the processes are absolutely necessary, cannot be changed, and give a total of 50 USD

With these data you know that the total cost is 200 USD. Now you remember your EE203 course and realize that you can easily eliminate 20 USD from the list. Which step or steps would you remove from the list above to achieve your goal? State the reason.

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 203

PROBLEM: 2

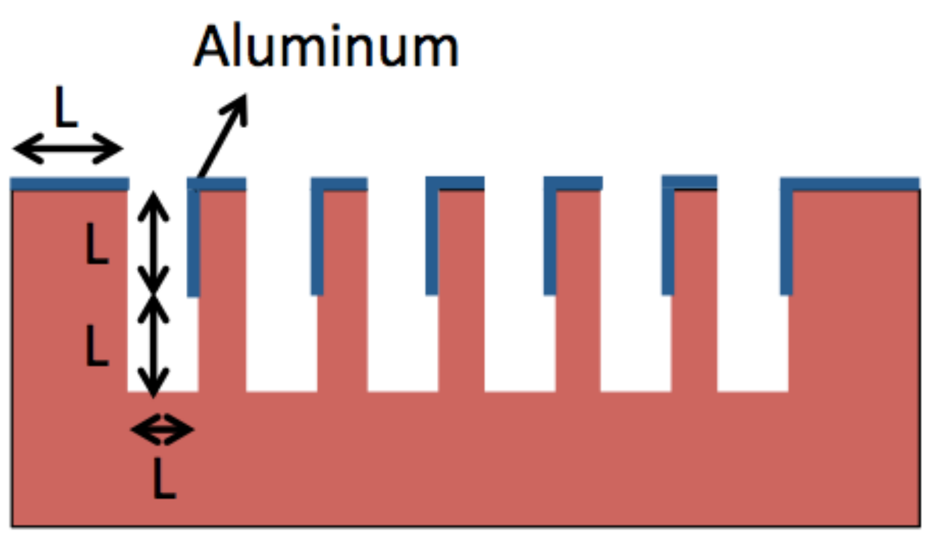
2. It has been two years since you joined the semiconductor foundry and you have been doing really well. Now you have been assigned with a task to find the most appropriate tool for each of the following processes. The good news is that they have given you a list of the tools available and the processes that need to be performed with their respective constraints. The tools available in the fab are the following:

1. Thermal evaporator
2. E-beam evaporator
3. PECVD
4. LPCVD
5. Sputter system with tilt capabilities
6. CVD
7. ALD
8. PLD
9. ICP-RIE with SF_6, CHF_3, CF_4, O_2, C_4F_8
10. Wet hood with NH_4F, HF, H_3PO_4, HCl, KOH
11. XeF_2 etching system
12. Ion milling
13. BOSCH system

For the following processes and constraints select the tool that will fit the best and state the reason why.

2a) Conformal deposition of 5nm thick Al_2O_3 film in a wafer with high aspect ratio features. Deposition must cover the wafer completely, even vertical walls of features, and cannot exceed +/- 0.5 nm error. No pinholes are allowed. (2 Points)

2b) Deposition of Al as in the following picture: (2 Points) (NOT DRAWN TO SCALE)



Continued on the next page

2c) Etch of SiO_2 from the top of a complete wafer with no patterning. There cannot be any damage on the underlying silicon or future process will fail completely and the wafer will be wasted. (2 Points)

2d) Deposition of 100 nm of Au on top of a semiconductor substrate that is very sensitive to ionized particles, if a few ionized particles reach the surface of the semiconductor it will cause unfixable defects. The substrate is also very sensitive to high-energy bombardment of particles. (2 Points)

2e) Etch very high aspect ratio (10:1) features made on a Si wafer, the process needs to be completely anisotropic and the etch has to be performed in a chamber with zero O_2 flow. Also, since there are devices on top of the wafer, the etch cannot be completely physical. (2 Points)

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 208

PROBLEM: 1

Q1

(a) With the add of diagram(s) or figure(s), briefly explain:

   (i) Photocurrent [2 pts]

   (ii) Photoconduction [2 pts]

   (iii) Photovoltaic [2 pts]

   (iv) Pockels effect [2 pts], and

   (v) Quantum-confined Stark effect [2]

(b) Design a simple PIN photodiode (PD) that can be operated at wavelength between 250nm and 800nm [4 pts].

(c) Discuss the feasibility of using your design in (b) as (i) solar cell [3 pts], and (ii) optical modulator [3 pts].

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 208

PROBLEM: 2

Q2

(a) Briefly explain: (i) Spontaneous emission [2 pts], (ii) Stimulated emission [2 pts], and (iii) absorption [2pts].

(b) Design a simple single quantum-well, double heterostructure semiconductor laser that can be operated at 850nm [5 pts].

(c) Suggest two methods for improving the temperature characteristic of a double-heterostructure laser [4 pts].

(d) Strained quantum-well structure is known to induce splitting of heavy-hole (hh) and light-hole (lh) in the valance band. Explain why splitting of hh and lh helps to improve the threshold current of a semiconductor laser? [5 pts]

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:_______

COURSE NUMBER: EE 221

PROBLEM: 1

Problem 1 (20 points)

Assume that a vector potential $\mathbf{A}(\mathbf{r})$ and a scalar potential $\phi(\mathbf{r})$ satisfy

$$\mathbf{H}(\mathbf{r}) = \frac{1}{\mu}\nabla \times \mathbf{A}(\mathbf{r})$$

$$\mathbf{E}(\mathbf{r}) = -\nabla\phi(\mathbf{r}) - j\omega\mathbf{A}(\mathbf{r})$$

where $\mathbf{H}(\mathbf{r})$ and $\mathbf{E}(\mathbf{r})$ are the magnetic and electric field intensities. Let $\mathbf{J}(\mathbf{r})$ and $\rho(\mathbf{r})$ represent electric current and charge densities. $\mathbf{J}(\mathbf{r})$ and $\rho(\mathbf{r})$ are only nonzero for $\mathbf{r} \in V_s$. Assume a lossless, homogeneous, and isotropic medium with permittivity ε, permeability μ, and wavenumber $k = \omega\sqrt{\mu\varepsilon}$. In addition to the above two equations, assume $\mathbf{A}(\mathbf{r})$ and $\phi(\mathbf{r})$ satisfy

$$\nabla \cdot \mathbf{A}(\mathbf{r}) + j\omega\mu\varepsilon\phi(\mathbf{r}) = 0 .$$

(a) (10 points) Starting from the Maxwell equations, show that $\phi(\mathbf{r})$ satisfies

$$\nabla^2\phi(\mathbf{r}) + k^2\phi(\mathbf{r}) = -\rho(\mathbf{r})/\varepsilon .$$

(b) (10 points) Show that solution of the above equation can be expressed as

$$\phi(\mathbf{r}) = \frac{1}{\varepsilon}\int_{V_s} \rho(\mathbf{r}')g(\mathbf{r},\mathbf{r}')dv' .$$

Here, $g(\mathbf{r},\mathbf{r}')$ is the scalar Green function that satisfies

$$\nabla^2 g(\mathbf{r},\mathbf{r}') + k^2 g(\mathbf{r},\mathbf{r}') = -\delta(\mathbf{r}-\mathbf{r}').$$

Note that $\phi(\mathbf{r})$ and $g(\mathbf{r},\mathbf{r}')$ satisfy the following radiation conditions:

$$\lim_{r\to\infty} r\left[\frac{\partial\phi(\mathbf{r})}{\partial r} - jk\phi(\mathbf{r})\right] = 0, \; r = |\mathbf{r}|,$$

$$\lim_{r\to\infty} r\left[\frac{\partial g(\mathbf{r},\mathbf{r}')}{\partial r} - jkg(\mathbf{r},\mathbf{r}')\right] = 0, \; r = |\mathbf{r}-\mathbf{r}'| .$$

Hint: For **(b)**, you may want to use the following mathematical identity

$$\int_V \left[a\nabla^2 b - b\nabla^2 a\right]dv = \oint_S \left[a\hat{\mathbf{n}}\cdot\nabla b - b\hat{\mathbf{n}}\cdot\nabla a\right]ds$$

where a and b are scalar fields, S is the surface enclosing V, and $\hat{\mathbf{n}}$ is normal outward pointing unit vector defined on S.

DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

EXAM ID NUMBER:________

COURSE NUMBER: EE 221

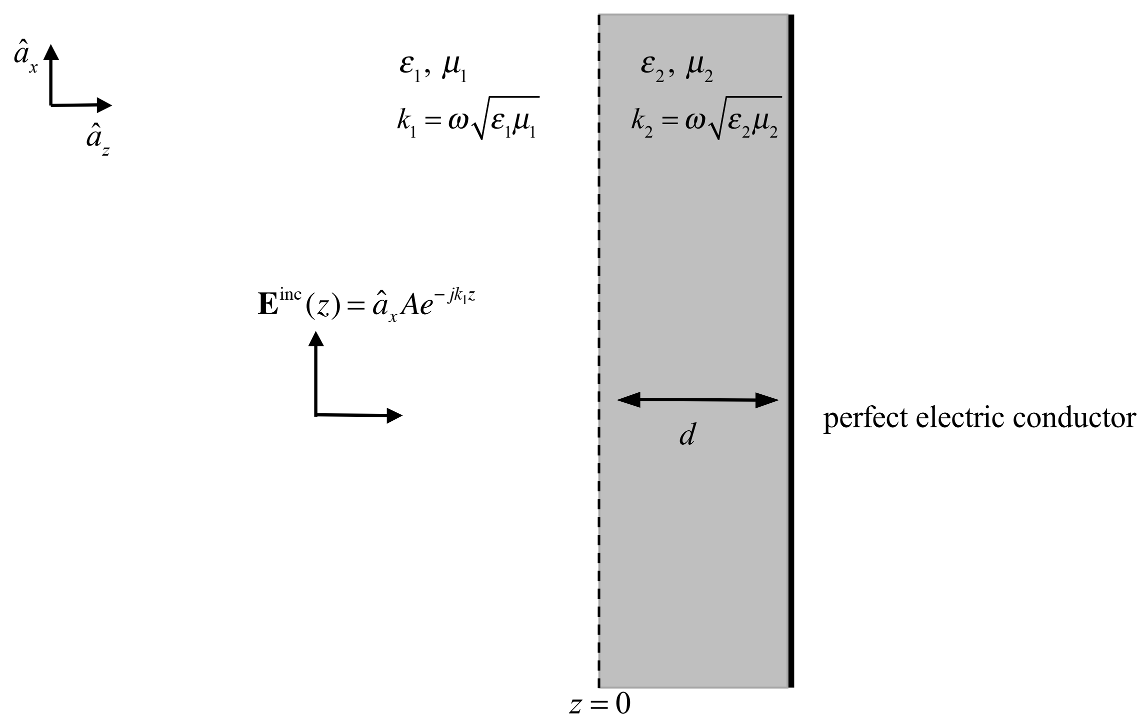
PROBLEM: 2

Problem 2 (20 points)

Electric field of a plane wave given by $\mathbf{E}^{\text{inc}}(z) = \hat{a}_x A e^{-jk_1 z}$ is normally incident on a perfect electric conductor coated with a slab of thickness d as shown in the figure. Here, $k_1 = \omega\sqrt{\varepsilon_1 \mu_1}$, ε_1, and μ_1 are the wavenumber, permittivity, and permeability in medium 1. Let $k_2 = \omega\sqrt{\varepsilon_2 \mu_2}$, ε_2, and μ_2 represent the same parameters in the dielectric slab.

(a) (12 points) Derive an expression for the total electric field in medium 1. Hints: (i) Express the amplitude of the reflected electric field in terms of A. (ii) The expression is easier to manage if you use wave impedances $\eta_1 = \sqrt{\mu_1/\varepsilon_1}$ and $\eta_2 = \sqrt{\mu_2/\varepsilon_2}$ for medium 1 and the slab.

(b) (8 points) Is there Find an expression that d has to satisfy to make the total electric field in medium 1 same as that if the slab were absent (i.e., coating would not change the fields in medium).



DO NOT WRITE YOUR NAME OR KAUST ID NUMBER ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR EXAM ID NUMBER ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON ONLY ONE SIDE OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON ALL SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED WELL AND WRITTEN CLEARLY – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP YOU IN GRADING

DO NOT WRITE ANY PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL NOT BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO ONLY FIVE PROBLEMS

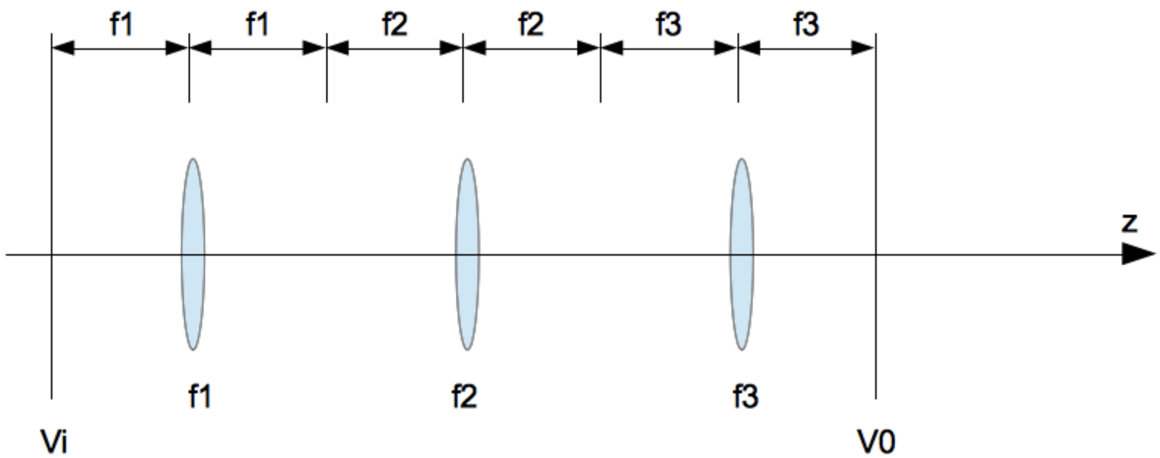
EXAM ID NUMBER:_______

COURSE NUMBER: EE 231

PROBLEM: 1

Problem 1

An input disturbance $V_i(x)=\exp(-x^2/w^2)$ is launched in a system sketched below:



The system is characterized by three thin lenses of focal f1, f2 and f3.

a) Calculate the output intensity $I=|V_0|^2$.
b) In the case of an input disturbance $V_i(x,z=0)=\exp(i K_x x)$, with K_x the x component of the wavevector, calculate by ray optics the propagation of rays in the structure.

DO <u>NOT</u> WRITE YOUR <u>NAME</u> OR <u>KAUST ID NUMBER</u> ON THIS PAGE OR ANY OTHER PAGE

PUT YOUR <u>EXAM ID NUMBER</u> ON THIS PAGE AND EVERY OTHER PAGE YOU SUBMIT

WRITE YOUR SOLUTIONS ON <u>ONLY ONE SIDE</u> OF EMPTY SOLUTION SHEETS PROVIDED

PUT PAGE NUMBERS ON <u>ALL</u> SOLUTION PAGES

YOUR SOLUTIONS SHOULD BE ORGANIZED <u>WELL</u> AND WRITTEN <u>CLEARLY</u> – NEAT AND EASY-TO-READ SOLUTIONS WILL HELP <u>YOU</u> IN GRADING

DO <u>NOT</u> WRITE <u>ANY</u> PART OF YOUR SOLUTIONS ON PROBLEM SHEETS – SOLUTIONS ON PROBLEM SHEETS WILL <u>NOT</u> BE GRADED

YOU ARE ALLOWED TO SUBMIT SOLUTIONS TO <u>ONLY FIVE</u> PROBLEMS

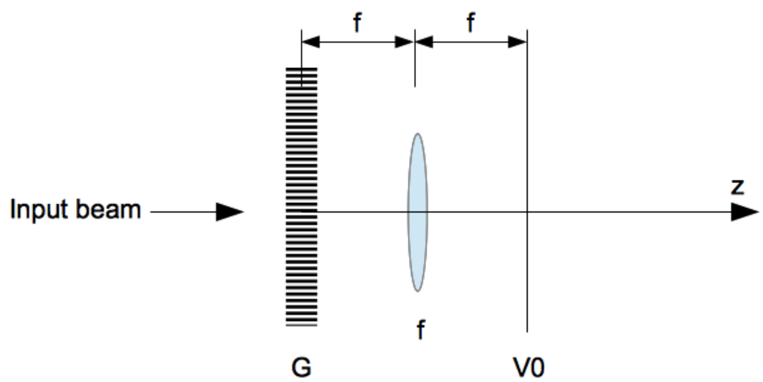
EXAM ID NUMBER:_______

COURSE NUMBER: EE 231

PROBLEM: 2

Problem 2

An input plane wave with disturbance Vi(x,z=0)=Exp(i*Kx*x), with Kx the wavevector component along x, is launched in the following system:



characterized by a grating G and a thin lens of focal f. The grating has the following transfer function T(x)=sin(2πx/L)+sin(4πx/L)+cos(8πx/L).

Calculate the intensity I=|V0|^2.